portant facts: (1) hydrocarbons, the main constituent of petroleum, are widespread in recent sediments but in amounts generally less than 2 per cent of the total organic content; (2) the Carbon-14 method has proved that the hydrocarbons and other organic fractions in recent sediments are recent in origin; (3) the ratio of hydrocarbons to other organic compounds is slightly different between recent and ancient sediments but in both it is vastly different from that in crude oil; (4) qualitatively, recent sediments and crude oils contain the same types of hydrocarbons, with minor exceptions; (5) the assemblages of various types of hydrocarbons in both sediments and crude oil are remarkably simple, considering the vast number of compounds theoretically possible; (6) the solubility of hydrocarbons is much higher in colloidal electrolyte solutions that in ordinary solutions, and recent data suggest that the relative solubilities in such dilute electrolytes may be related to the amounts of these compounds present in crude oils.

These and other discoveries point to the formation of crude oil by a mechanism involving the physical concentration of hydrocarbons already disseminated through the recent sediments or hydrocarbons formed from closely related compounds in the first few hundred feet of burial. The presence of natural solubilizers in water being squeezed from a compacting mass of sediments may selectively concentrate in colloidal form the various components which together form petroleum. The efficiency of the process is so very poor that only a small percentage of the available hydrocarbons are finally concentrated in a trap as crude oil.

Chemical studies of the organic compounds present in living organisms and in recent sediments containing their dead remains have proved to be very fruitful and should be continued, using the most advanced techniques available.

Oil Migration

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Physical analysis of oil migration through a water-saturated, hydrophilic, porous sediment suggests the following mechanisms of migration: (1) continuous-phase flow, (2) colloidal dispersion in water, and (3) molecular solubility in water.

The first mechanism, continuous-phase flow, is a major factor in controlling the movement of oil through porous reservoir rocks, the migration of oil into traps, or leakage of oil out of traps. Relatively high saturation of hydrocarbons (15–25 per cent of pore volume) must exist to create the continuity of the oil phase necessary for migration by this mechanism. The relatively low residual hydrocarbon saturations observed in many shales considered as probable source beds suggest that migration by this mechanism has not occurred therein.

The second mechanism, colloidal dispersion in water, appears to be a major factor in controlling the primary migration of oil out of many typical source beds. These migrating colloids may vary from the partially reduced organic complexes found colloidally dispersed in sea water and sea-bottom muds to oil solubilized by naturally occurring soap micelles or other solubilizing agents. If this mechanism has occurred in a shale, the organic content of the shale source bed may be low, and the residual hydrocarbon content in per cent of pore volume may be almost nil.

Two primary requirements for the operation of this second migration mechanism are the following.

1. The source-bed mineral surfaces must be hydrophilic. Experimental evidence indicates that the predominantly sodium-based mineral surfaces found in a normal marine sediment are generally hydrophilic and, therefore, could be source beds; whereas the predominantly calcium-magnesium-based mineral surfaces of many non-marine sediments may commonly be oleophilic and, consequently, probably are non-source beds.

2. The organic colloid, soap micelle, or other solubilizing agent must be stable and mobile within the source bed and must become unstable, immobile, or dissociated some-

where within the reservoir bed. The flocculation or dissociation of these colloids appears to be greatly affected by the Donnan-equilibrium-controlled anion-exclusion and cation-absorption properties of high-electrical-charge-density materials such as shales.

When the migration is terminated by either dissociation or flocculation, the resulting finely dispersed unstable organic particles or oil droplets will start to aggregate. Consequently, buoyancy will cause them to rise (or fall) through the water phase to the top (or bottom) few inches of the porous reservoir. If the oil or oil-forming material accumulates in the top few inches of the reservoir bed in sufficient concentration to subsequently produce extensive oil-phase continuity, then additional migration by the continuous-phase flow mechanism can occur.

The third mechanism, molecular solubility in water, may be a significant factor in selectively transporting certain hydrocarbon fractions and thereby modifying the oil characteristics.

If only the first mechanism were operative, source beds should be detectable by their high residual hydrocarbon content. If the second mechanism were commonly operative, such source beds could not be identified simply by measuring the residual oil saturation; and if source beds of this type are throughout most marine sedimentary sections, the limited occurrence of major oil production must be related to conditions required for continuous entrapment and preservation of oil since the time of origin.

The entrapment of oil is primarily controlled by the first mechanism—continuous-phase flow. Therefore, a critical evaluation of this mechanism under both hydrodynamic and hydrostatic conditions throughout the geologic history of an area is recommended for finding both broad oil provinces and specific oil fields.

Prospecting for Stratigraphic Traps

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Stratigraphic traps are directly related to their respective environments of deposition. An understanding of the depositional environment is essential to successful prospecting for oil or gas from this type of reservoir. Isopach studies of shale units directly above or, both above and below a lenticular reservoir sandstone, are of considerable value in reconstructing depositional environments. Such shale intervals, either directly above a reservoir sandstone, or embracing it, are genetic units and variations in thickness are completely independent of present-day structural configuration. Isopach maps of such genetic units serve as realistic indicators of where certain lenticular sands were deposited. Depositional trends of beach sands, offshore bars, and strike valley sands are readily determined from such studies. Structural maps, constructed on a reliable time marker within the genetic interval, serve as a means of localizing oil or gas accumulation within any of these reservoir types. In all such studies electrical log data are essential, since arbitrarily selected genetic units are seldom named formational units. The thinner the genetic interval, the greater the necessity for accurate "picks" from electrical log data.

Deltaic reservoirs are poorly understood and only rarely recognized by the geologist. This type of reservoir is, nevertheless, abundantly preserved in the sedimentary section. Regional isopach studies of deposition environment are an essential prerequisite for the construction of meaningful exploration maps of this type of reservoir. An understanding of the trends of distributary fingers and the influence of differential compaction in producing drape structures, likewise, is important.

Educating Future Earth Scientists

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With knowledge expanding at a quickening pace, there is obvious necessity for broad and substantial preparation in mathematics and the physical sciences as a basis on which to build the derivative earth sciences. Three of these earth sciences—geology, geophysics,